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TO: ~~Curtis D. Laughlin, NASA-Ames Research Center, 211-12~~

FROM: Charles M. Telesco, Astronomy Department, University of Florida

SUBJECT: **Final Technical Report for NASA-Ames Agreement No. 2-972**

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OVERVIEW OF PROPOSED RESEARCH

The purpose of the proposed research on the Kuiper Airborne Observatory (KAO) was to support absolute photometric calibration of the Infrared Space Observatory (ISO), which was launched by the European Space Agency (ESA) in November 1994. NASA and the Japanese Space Agency (ISAS) are partners with ESA on the ISO mission. ISO, the major infrared mission of this decade, has four focal plane detector systems that together span the spectral region between 2 and 240 μm. One of these four instruments is ISOPHOT, the spectrophotopolarimeter. C. Telesco, the PI of the subject KAO proposal, is also a Co-I on the German-led ISOPHOT instrument team. One of his key Co-I tasks on the ISOPHOT team has been to establish the method by which ISOPHOT is photometrically calibrated in absolute flux units in the far-infrared (30 - 240 μm) during the mission; i.e., Telesco has been responsible for establishing which celestial objects should be used to provide that absolute calibration and what spectral energy distributions (SEDs) should be assumed for them.

Perhaps surprizingly, stars and planets were not chosen to be ISOPHOT's principal photometric calibrators in the far infrared. Stars are generally too faint for ISOPHOT, and planets are generally too bright and not numerous enough for ISOPHOT and mission scheduling requirements, although both stars and planets do contribute to ISOPHOT's calibration. Building on NASA's experience with the Infrared Astronomical Satellite (IRAS), Telesco established asteroids as the the primary photometric calibrators in ISOPHOT's principal flux density regime, i.e., roughly the range 1 - 500 Jy. As with any photometric standard, however, it is necessary to know the object's SED. For photometric calibration of IRAS, it was assumed that the SED for a particular asteroid at a particular time could be computed using the so-called Standard Thermal Model (STM). *The goal of the approved KAO research program was to actually test the asteroid Standard Thermal Model that would determine ISOPHOT's absolute calibration* to determine if it could indeed be used to predict far-infrared fluxes with the required accuracy of ~10%, which is much more ambitious than that achieved by IRAS (~20%) and for most previous KAO observations (20-30%). Until the current program, asteroids had not been properly observed and accurately calibrated at wavelengths longer than 60 μm. Although asteroids were used to calibrate IRAS at 100 μm, the 100 μm fluxes assumed for the IRAS calibration asteroids were not directly observed but were estimated by extrapolating the energy distribution calculated with the STM at 60 μm out to 100 μm.

Those shorter-wavelength asteroid data were calibrated with respect to stars by assuming solar-type 12-25-60 μm colors and by using groundbased observations of α Tau made only at 10 μm. Because the 100 μm fluxes for the IRAS calibration asteroids was not based on direct observation at that wavelength, nor were rotational light curve variations taken into account, the suitability ogf the far-IR calibration for ISOPHOT has been unclear. Thus, the goal of the supported KAO research was to examine that issue for the first time through direct far-IR observations of asteroids.

PROCEDURE

Our approach was to use the KAO with either the Yerkes photometer (Harper, PI) or the Texas photometer (Harvey, PI) to do photometry in several far-IR passbands out to at least 100 μm, or longer if possible, of four or five of the brightest asteroids. The asteroids actually observed were 1 Ceres, 2 Pallas, 4 Vesta, and 10 Hygiea. These asteroids were used to test the STM. To calibrate the KAO asteroid photometry itself, the planets Uranus, Neptune, and Mars and, on one occasion, the Galilean satellite Callisto, were used as standards. For the initial phases of the KAO program, Larry Lebofsky at Steward Observatory provided the SEDs for each of the asteroids based on his STM code. This responsibility was later taken over by David Osip at the University of Florida who also has continued to provide asteroid SEDs directly to the ISOPHOT calibration scientists throughout the ISO mission. Mian Abbas of NASA Marshall Space Flight Center calculated the SEDs for the KAO standards Uranus and Neptune.

RESULTS

The key results are shown in Fig. 1 as the ratio of the KAO-observed flux density to that predicted by the STM. All usable KAO observations are included in this figure;

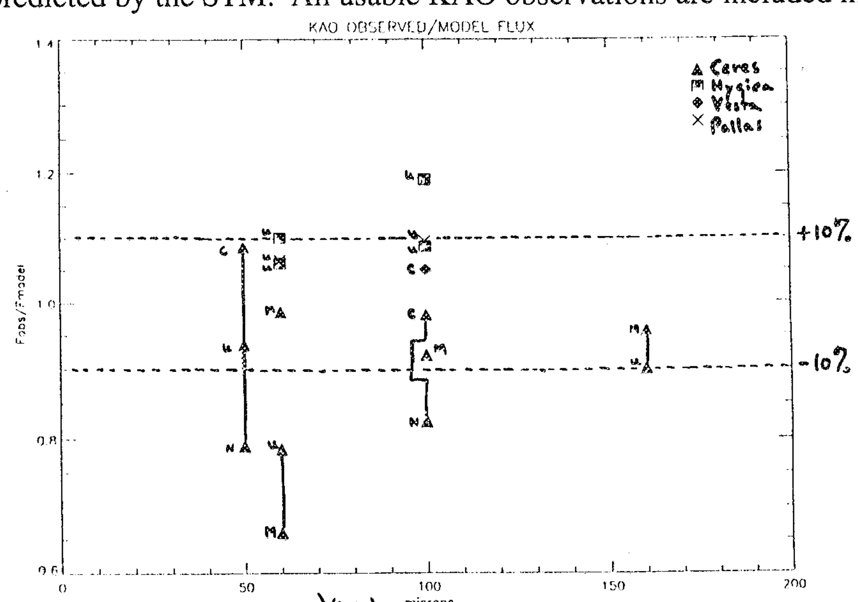

Figure 1. Comparison of asteroid far-IR flux densities observed with the KAO to those predicted by the Standard Thermal Model.

some KAO observations proved to be of too low a signal-to-noise ratio to be of use, and they are not included here. The different symbols correspond to different asteroids, as indicated by the legend in the upper right corner of the figure. The letters next to each symbol correspond to the KAO photometric standard used to reduce the KAO observations: Uranus (U), Neptune (N), Mars (M), and Callisto (C). If the STM and the models used to predict the KAO calibrator fluxes were "perfect," then we would expect $F_{obs}/F_{model} = 1$. Our goal for ISOPHOT was to be able to produce models which describe the asteroid flux density at any wavelength between 30 and 240 μm to within ±10%, and so ideally the value of F_{obs}/F_{model} would fall between the two corresponding dashed lines in the figure.

It is clear that much of the scatter in the values at a given wavelength is due to imperfect models for the KAO calibrators, since we get a range of inferred asteroid fluxes for the same asteroid observation. Nevertheless, we see that most of the observations fall within the ±10% range. The most discrepant points are the very low values for Ceres at 60 μm. However, a repeat of those observations a year later indicated a much higher value falling within the ±10% range. *We conclude from the results of this KAO study that asteroids can be used as far-infrared photometric standards for ISOPHOT, and that the Standard Thermal Model provides an adequate description of the asteroid spectral energy distribution in the far infrared.*

This KAO program has been highly successful. It has permitted us to assess the reliability of asteroids as far-IR photometric standards using the STM. Consequently, we are now actually using the STM to calculate IR energy distributions for ISOPHOT asteroid standards during the ISO mission, which is now expected to extend until about February 1998. The KAO program has given us confidence that this approach is valid, which is the primary intended result of the program. Reference to this KAO program and its relevance to calibration of ISOPHOT has been explicitly made by the ISOPHOT team in *Lemke et al. 1996, A&A, 315, L64.* It is our intention to prepare a comprehensive paper describing these KAO results after the ISO mission has been completed.

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